

AN INTRODUCTION TO THE ASTRO EDGE¹ SOLAR ARRAY

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ABSTRACT

The *Astro Edge* solar array is a new and innovative low concentrator power generating system which has been developed for applications requiring high specific power, high stiffness, low risk, light weight, reliability, low stowed volume, negligible thermal snap, and affordability. The basic system is of modular construction which utilizes conventional materials and technology, and standard photovoltaic solar cells and laydown processes. Mechanisms, restraint/release devices, wiring harnesses, substrates, and support structures are designed to be simple, functional, lightweight, and modular. A brief overview of the *Astro Edge* solar array is discussed.

INTRODUCTION

The *Astro Edge* solar array is an innovative low cost, lightweight, compact, low concentrator solar array of modular construction which provides significant advancements in performance, reliability and affordability of solar array systems. A breadboard demonstration model is shown in Figure 1.

The *Astro Edge* solar array takes conventional materials and achieves a significant advance in efficiency by innovative packaging and incorporation of unique deployment systems. Mechanisms are designed to be simple and functional, tailored to the strength of lightweight substrates. Simplistic design and use of reflectors to decrease the number of solar cells enables an increase in efficiency while decreasing the system cost.

The *Astro Edge* solar array achieves low cost and low weight by using a lightweight reflector system to concentrate energy from the sun, obtaining the required output from 33 percent fewer solar cells than standard flat arrays. Net solar concentration is 150 percent (1.5 AM0), assuming a conservative 15 percent reflectivity, dimensional inaccuracy and thermal distortion loss. Specific powers for a 1000-watt EOL solar array wing of 150 W/kg with near-term multi-junction cells and 122 W/kg with existing GaAs/Ge cells are realistically achievable.

The deployed *Astro Edge* solar array forms a "channel" shaped configuration to provide very high stiffness allowing for the use of extremely lightweight substrate materials and hinges. Near-frictionless rolling tape type hinges and a simple damped spring-driven coordination sequence promote reliable deployment.

A more compact stowed package is achieved as a result of extremely thin substrates which are in contact when stowed. The cells are protected for launch by cushioned reflector surfaces. The reflective film is mounted to a thin foam cushion on the reflector panels. In the stowed configuration, the reflector panels are folded onto the solar cell panels, and the stack is compressed together for launch. The stowed configuration forms a compact package which is both secured and cushioned to provide a highly damped launch environment. In the deployed condition the reflector surfaces and structural configuration thermally decouple extreme temperature differentials to eliminate "thermal snap" phenomena resulting from exiting an eclipse.

The *Astro Edge* solar array is applicable to a broad power range and provides a low risk alternative for future spacecraft missions requiring high performance, light weight, reliability, low stowed volume and affordability. An overview of pertinent components is discussed in the ensuing paragraphs.

¹ Patent applied for.

DEPLOYMENT

The deployment sequence is shown in Figure 2. The array is preloaded against the spacecraft sidewall for launch and released with a lightweight hot wire cutter. On release, the hinge lines at the yoke/orientation drive, the yoke/panel, and the reflector panel/panel joints start to spring open. The motion is controlled by a system of lightweight graphite control rods and damped with a small viscous damper at the root hinge. When the reflector panel/panel hinges are fully open, the reflector to cell panel hinges will then spring open. This deployment is undamped, but because of the low torque springs and the lightweight reflectors, the energy involved is small. The reflector panels will deploy until terminated by diagonal tension lines. These lines will accurately determine the angle of the reflector. Preload from the hinges will be adequate to maintain the structural configuration through all spacecraft motions. A latch or locking mechanism is not required. In fact, latches are not necessary on the reflector panel/panel hinges because their geometry will prevent any bending.

The deployment forces associated with this lightweight solar array are very low. Spring designs are such that the array would survive an uncontrolled deployment. Control is required primarily to ensure that the array does not impact the spacecraft or any payloads. Control does not have to be precise and small errors in relative panel positions are acceptable.

The coordination linkage, shown in Figure 3, is a series of parallel linkages in which the panels form one part of the linkage and an assembly of 0.25-inch graphite composite tubes form the other. Because of the allowable inaccuracy, the hinges between the links need not be precision devices. In addition, because of the low drive torque involved, they can be of minimum strength.

CELL SUBSTRATES

The *Astro Edge* solar array geometry inherently provides a high degree of stiffness in the deployed position due to the reflector and cell substrate panels configured at steep angles to each other. By using the high in-plane stiffness of the flat panels, the out-of-plane bending stiffness requirements are much lower than typical deployable solar panels. This provides major opportunities for selection of lightweight materials and panel designs using thin sandwich construction for reducing volume and providing low weight. The solar cell substrates provide a dimensionally stable surface with sufficient stiffness and strength to support and prevent damage to the bonded solar cells. In addition, the substrate also electrically isolates the cells and provides an effective heat flow path for dissipation of waste heat. The substrates incorporated in the *Astro Edge* design are 1/8-inch-thick aluminum honeycomb core with 0.003-inch-thick Kevlar facesheets. The low CTE of the Kevlar laminate, combined with the low moisture absorption of the cyanate ester matrix, provides dimensional stability near that of a graphite facesheet at lower weight and cost. The Kevlar also provides an inherent electrical barrier for the solar cells without the added weight or the concern over pin holes of a Kapton film. The facesheet on the non-cell side of the panel incorporates a resin matrix loaded with graphite, resulting in a black Kevlar appearance which increases emissivity to 0.9 for higher heat dissipation from the panel.

REFLECTOR SUBSTRATES

Reflector substrate materials are identical to the cell substrate materials except for the additional mirrored surface and underlying foam. The back surfaces of the reflector substrates are not carbon loaded so that wiring harness can be directly bonded to the substrate. The integration of a 1/16-inch-thick polyurethane foam combined with a 0.002-inch-thick aluminized Teflon film comprise the remainder of the reflector panel. The layer of foam provides compliance for the reflective film and protects cells during launch.

HINGES

Hinging lightweight panels requires a different design from the traditional hinges and torsion springs commonly used. The panel to panel hinges employed are essentially frictionless, as they rely on rolling motion, and wrapping and unwrapping of metal tapes. Low torque and lightweight leaf springs, incorporated into each hinge, are used as the driving force for deployment. An engineering model of the

panel to panel hinge is shown in Figure 4. The hinge incorporates a female receptacle for easy assembly and changeout that becomes an integrated component of the substrate panels during lay-up.

The yoke to panel hinges are of the same rolling tape type as on the panels, but for this application incorporate a locking feature to maintain deployed position since geometry will not automatically lock it.

The orientation drive to yoke hinge, located at the root of the array, is the most heavily loaded and needs to lock out in a backlash-free manner. The baseline hinge is shown in Figure 5. At the root of the yoke structure, two journal bearings form a clevis hinge with the orientation drive flange. A leaf spring is mounted on the hinge axis to slow the whole deployment. The leaf spring is sized to provide the required margins over the damper and bearing friction, and the resistance from the stabilization link. The stabilization link is mounted to the orientation flange by a flexible pivot built of S-glass composite. It therefore will always have a tendency to move to the deployed position. At the other end of the link, rollers roll in the track mounted to the yoke and in the deployed position run over a spring latch which latches them against a hard stop eliminating any backlash in the joint.

WIRING HARNESS

Wiring harness has been designed such that at all times it assists deployment. Power is carried on flat beryllium copper strips attached to the backside of the reflector panels as shown in Figure 6. Beryllium copper cusps, preformed to deployed configurations, provide positive torque during deployment and bridge power between panels and other hinging points. The wiring harness is made from thin beryllium copper spring material, and is preformed along the hinge-lines to provide additional deployment force.

SUPPORT STRUCTURE

Because the array is an extremely lightweight device, all support structures are not required to be very stiff to achieve the common 0.1 Hz deployed system frequency.

The yoke structure is an extremely lightweight structure composed of high modulus graphite tubes with a 0.010-inch wall thickness. This member, as with all other support structures, is sized by the minimum practical manufacturable thickness and easily provides more than adequate stiffness.

STOWAGE SYSTEM

The stowed design concept, shown in Figure 7, preloads a sandwiched package of solar panels and cushioned reflector panels together against snubbers on the spacecraft sidewall. Shear load transfer is accomplished by features on the central snubber and selected external snubbers.

A preloaded structural load spreader, shown in Figure 8, is attached to the backside of an outboard panel which spreads the load from the central tie-down to attachments at the outermost panel edges. The attachments are at the feet of the structural load spreader and slide in a radial direction so that as load is applied to the hub the feet slide outward until the hub is in contact with the central preload stack. Upon release, the structure hub will jump up and clear the panel, but the feet will remain attached to the panel. As deployment takes place, the structure remains attached to an outer panel. The extra weight at the outboard end of the array has minimal effect because of the inherent stiffness of the deployed array, and the fact that the entire structure is at a minimum manufacturable thickness.

As mentioned previously, the solar array is preloaded against the spacecraft side wall and reacted at several snubbing points, but directly attached at the orientation drive and at a centrally located single restraint/release mechanism. Launch restraint/release is provided by a lightweight thermal cutter system as illustrated in Figure 8. The basic components are a Kevlar cord which is used to preload the array system and two cutting wires. The cutters are sequenced to give redundancy. Initially, the lower wire is heated. If this fails to cause release, then the upper wire is heated. The cutter wires are

preloaded against the Kevlar tie cord by a light torsional spring, sufficient to prevent vibration on launch, but not enough to cause damage to the Kevlar.

PERFORMANCE SUMMARY

The *Astro Edge* solar array can be adapted to a variety of applications ranging from Pegasus-class size to EOS-class size power ranges. Design studies have been performed to evaluate performance characteristics of an *Astro Edge* solar array modified for both a Pegasus-class size and EOS-size spacecraft. Table 1 shows a performance summary detailing mission requirements, EOL wing power, mass properties (including orientation drive), first deployed mode, first stowed mode, and stowed volume.

A preliminary COSMOS/M structural model of the deployed array is shown in Figure 9. The array forms into an inherently stiff configuration when deployed. As a result, the first deployed mode is driven primarily at the yoke structure root as shown. Deployed natural frequency can be tailored by simply modifying the yoke structure section.

A preliminary COSMOS/M structural model of the stowed array is shown in Figure 10. Stowed first mode is driven primarily by the stowage structure stiffness. Stowed natural frequency can be tailored by simply modifying the stowage structure section or by increasing the number of leg supports.

A conservative thermal analysis was performed to determine GaAs/Ge cell operating temperatures. Figure 11 shows the GaAs/Ge array temperature distribution for a sun synchronous Earth-oriented low-Earth orbit. The preliminary analysis indicates a maximum cell operating temperature of 89.1°C, and an average cell operating temperature of approximately 86°C. Additionally, a worst case thermal analysis was performed for an equatorial low-Earth orbit. Figure 12 shows the temperature profile for this worst case condition. The analysis indicates an average cell operating temperature of 94°C.

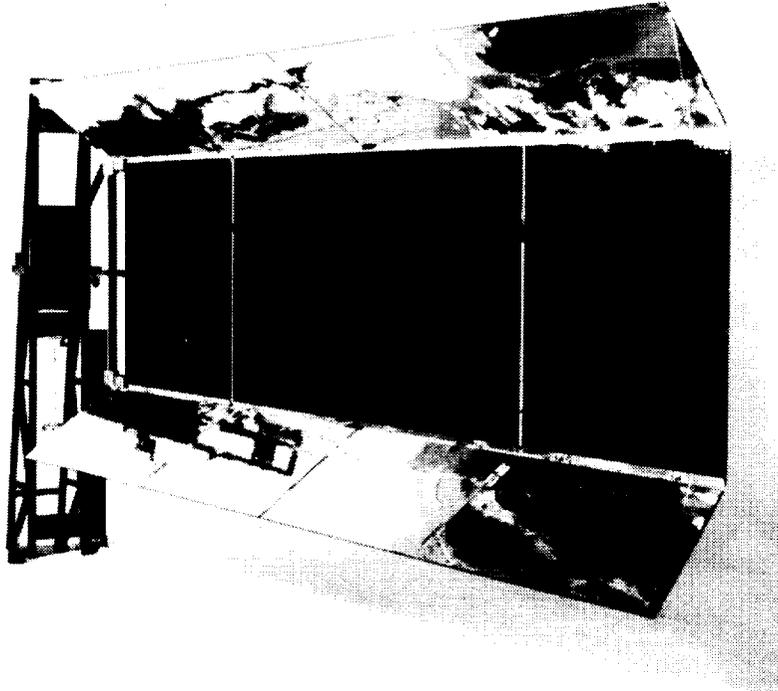
Another inherent advantage of the *Astro Edge* solar array lies in its ability to react large thermal differentials in a controlled manner without affecting overall spacecraft control. The reflective surface and foam interlayer on the reflector panels effectively thermally decouple extreme temperature differentials to eliminate thermal snap resulting from exiting an eclipse. The end result is a dynamically stable array during eclipse transition.

CONCLUSION

The *Astro Edge* solar array represents a unique technology applicable to a variety of power ranges and provides a low risk alternative for applications requiring high specific power, low weight, low stowed volume, reliability and affordability.

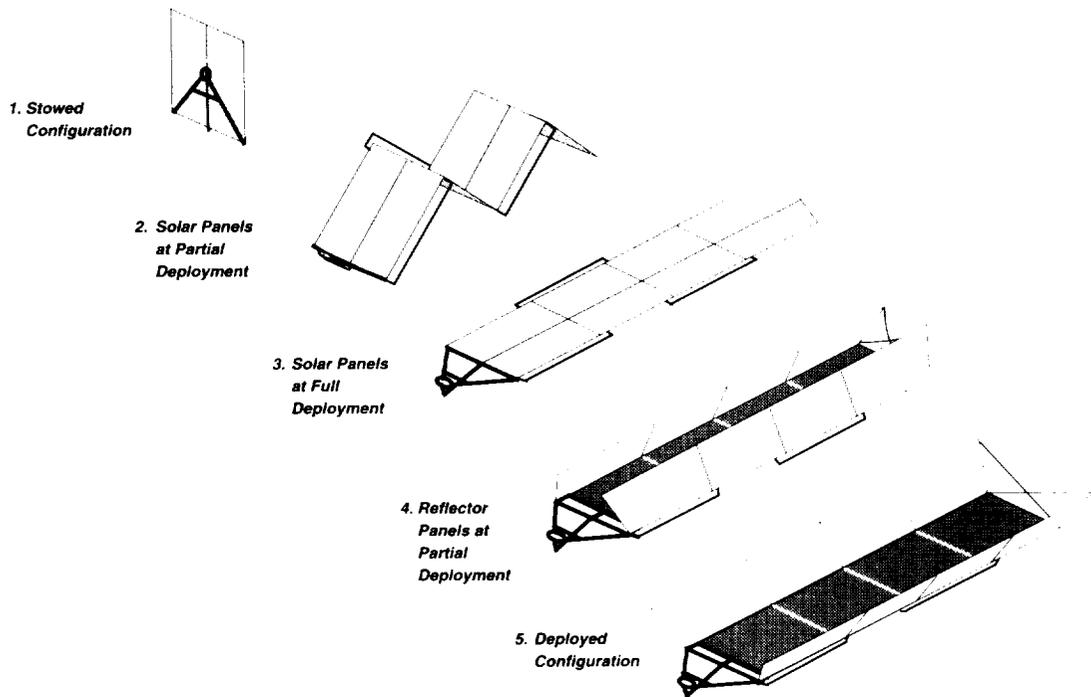
TABLE I.—ASTRO EDGE SOLAR ARRAY PERFORMANCE SUMMARY
WITH 3.5-MIL-THICK GaAs/Ge SOLAR CELLS

Parameter	Pegasus-Class Size Performance	EOS-Class Size Performance
Mission	7 years LEO	7 years LEO
EOL Power	1364 W	5017 W
EOL Specific Power	113 W/kg	138 W/kg
Deployed First Mode (governed by yoke structure stiffness)	0.32 Hz	0.092 Hz
Stowed First Mode (governed by stowed structure geometry and stiffness)	25.1 Hz	25 Hz
Stowed Volume	~1.2 ft ³	~15 ft ³



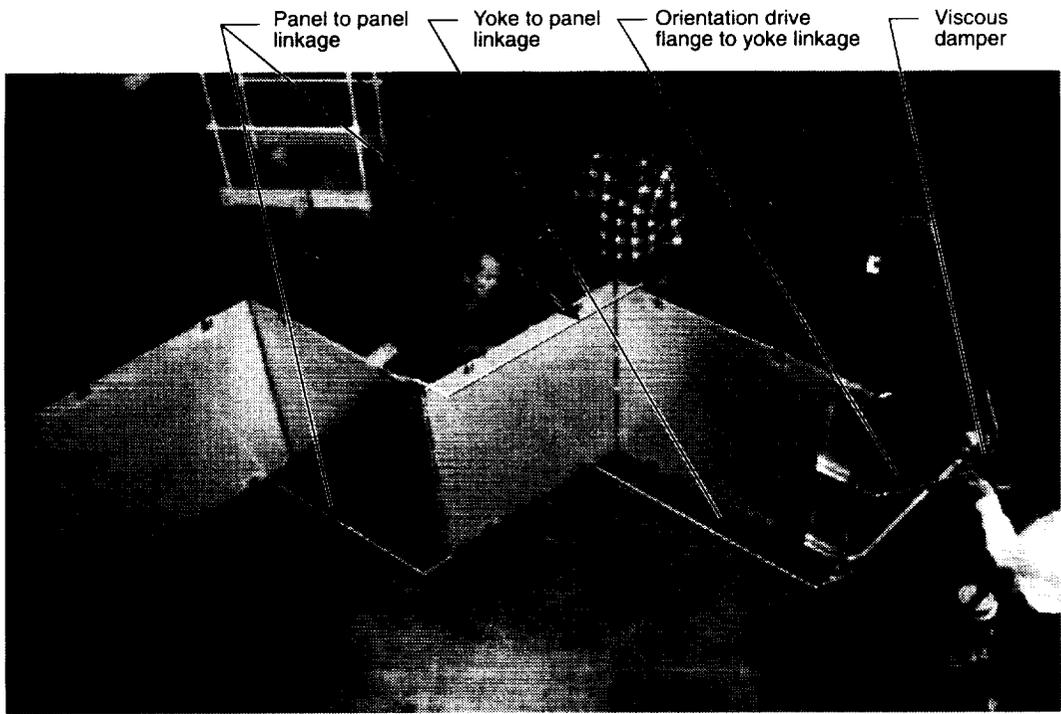
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Figure 1. *Astro Edge* Solar Array Breadboard Demonstration Model.



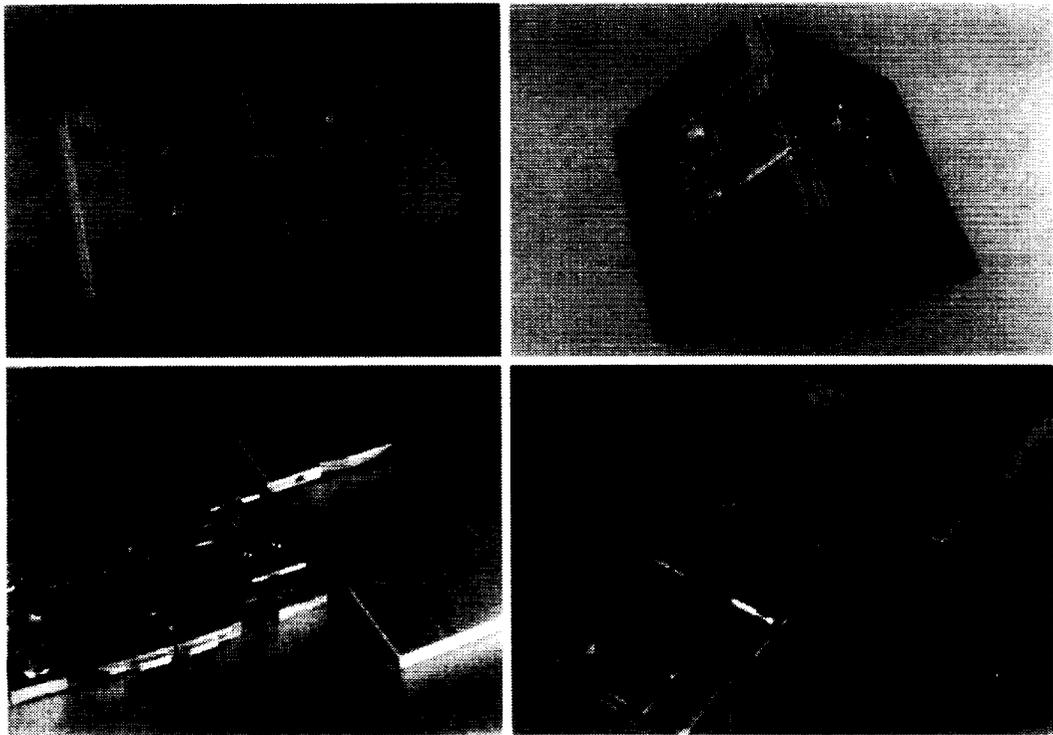
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Figure 2. *Astro Edge* Deployment Sequence.



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Figure 3. *Astro Edge* Coordination System.



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Figure 4. *Astro Edge* Panel to Panel Hinge Assembly.

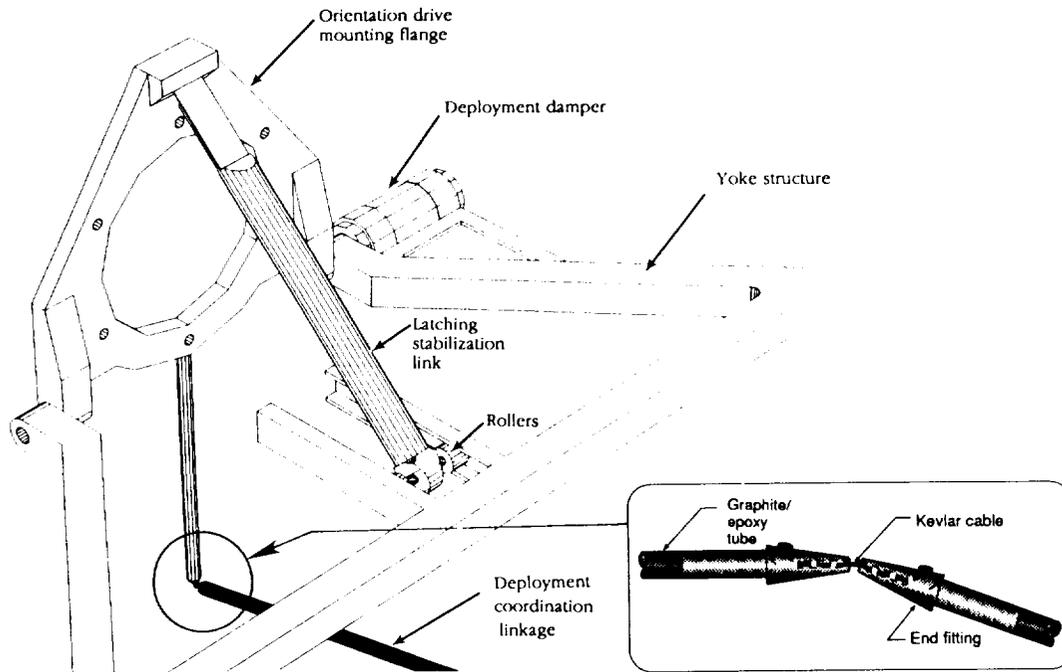
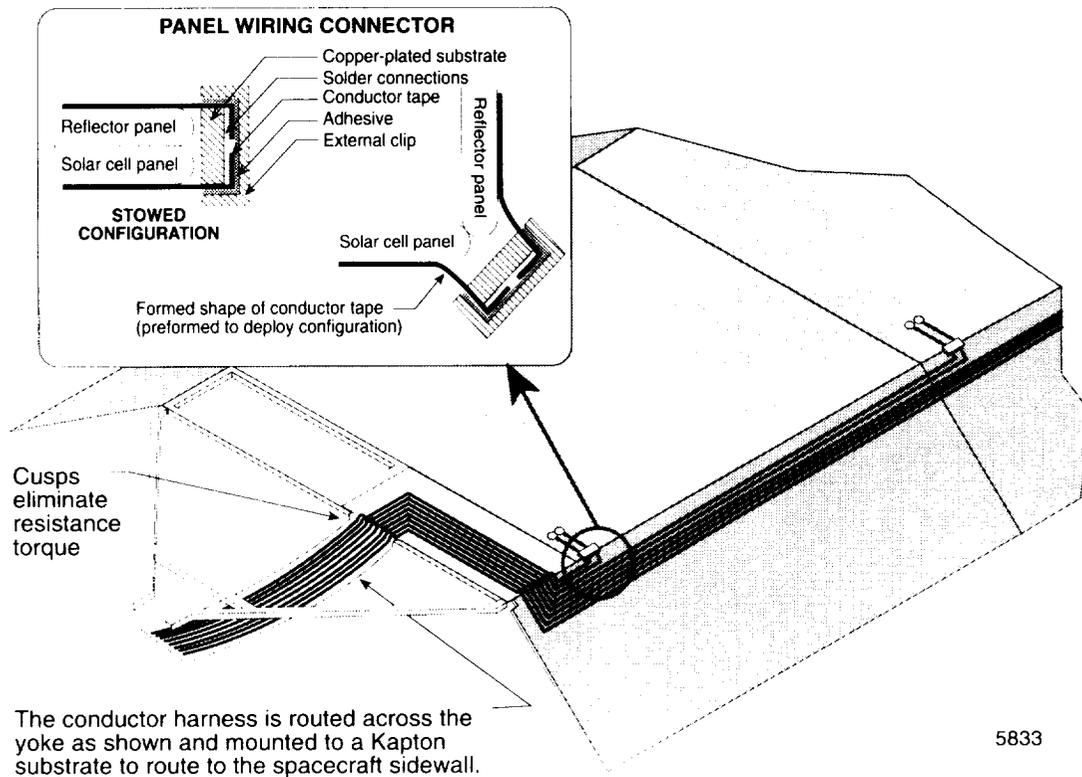


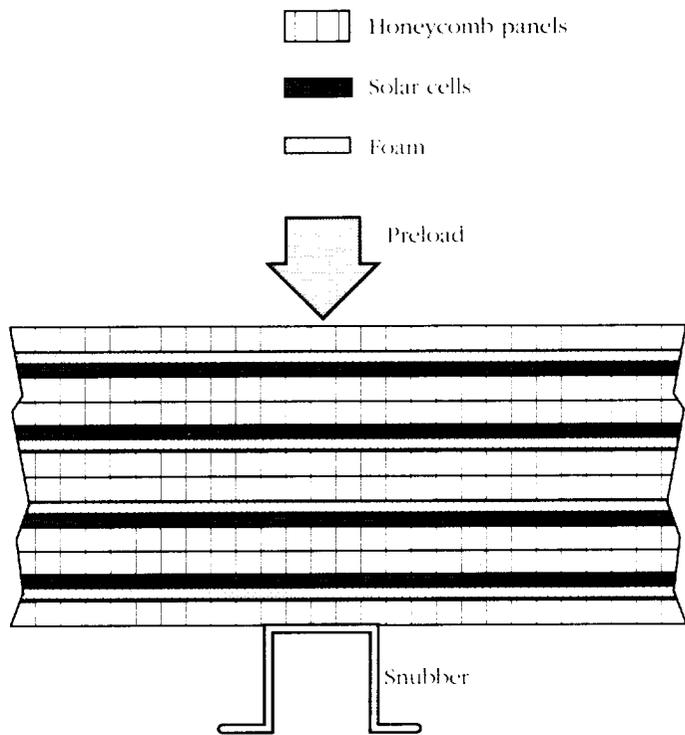
Figure 5. *Astro Edge* Yoke to Orientation Drive Hinge.

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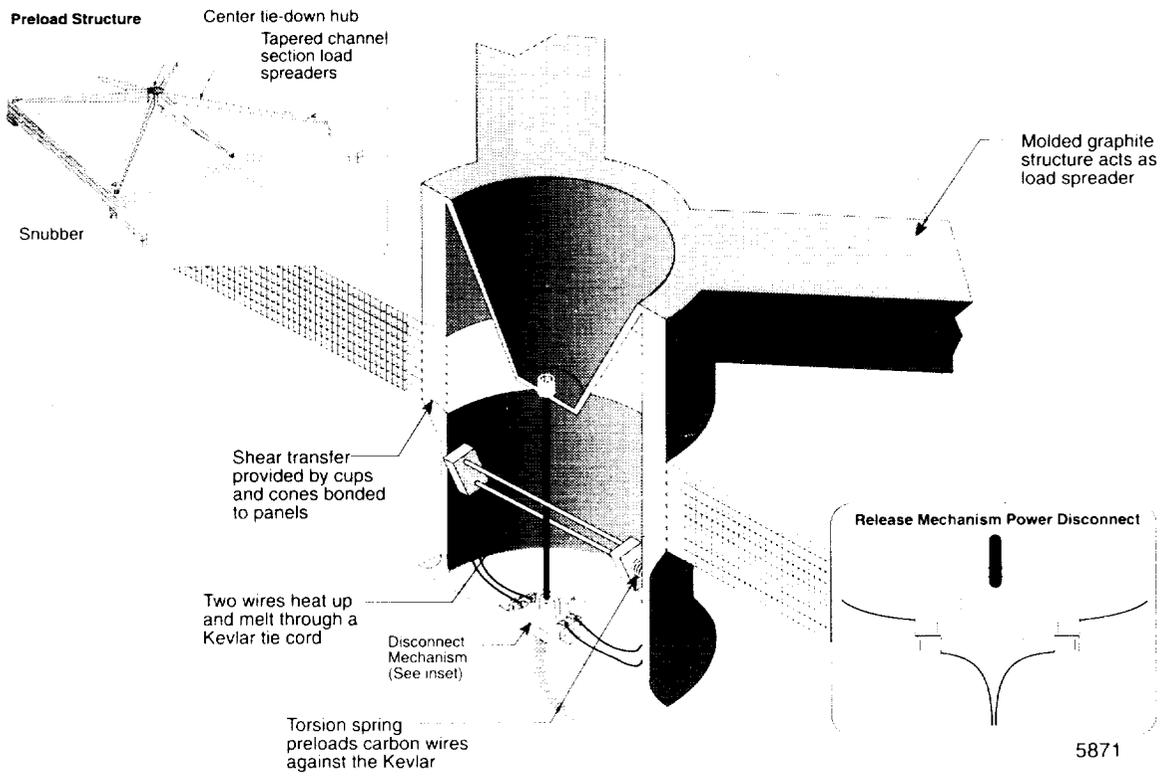
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Figure 6. *Astro Edge* Wiring Harness.



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Figure 7. Astro Edge Stowed Package Concept.



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Figure 8. Astro Edge Solar Array Launch Restraint.

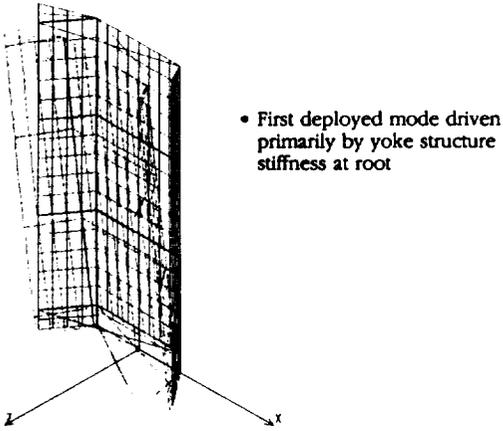


Figure 9. *Astro Edge* Solar Array First Deployed Mode.

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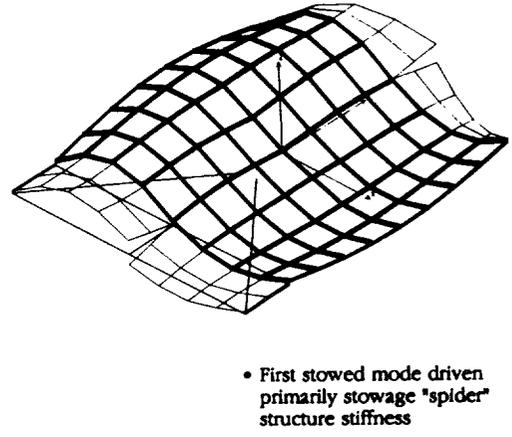


Figure 10. *Astro Edge* Solar Array First Stowed Mode.

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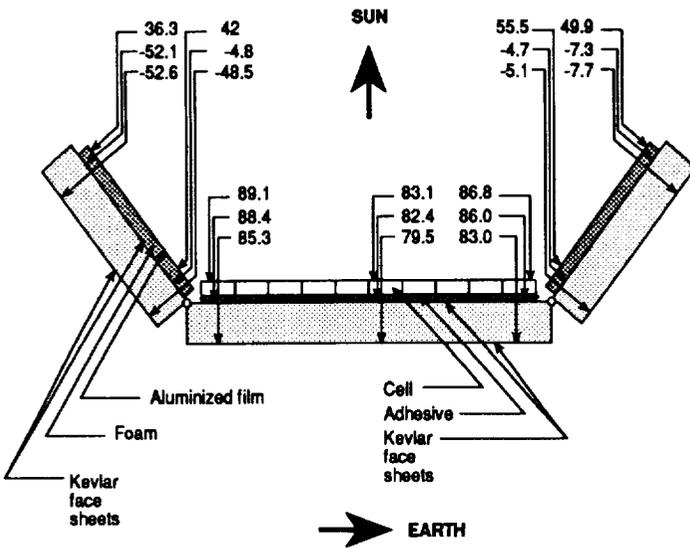


Figure 11. *Astro Edge* Solar Array Temperature Distribution for Sun Synchronous Earth Oriented Orbit.

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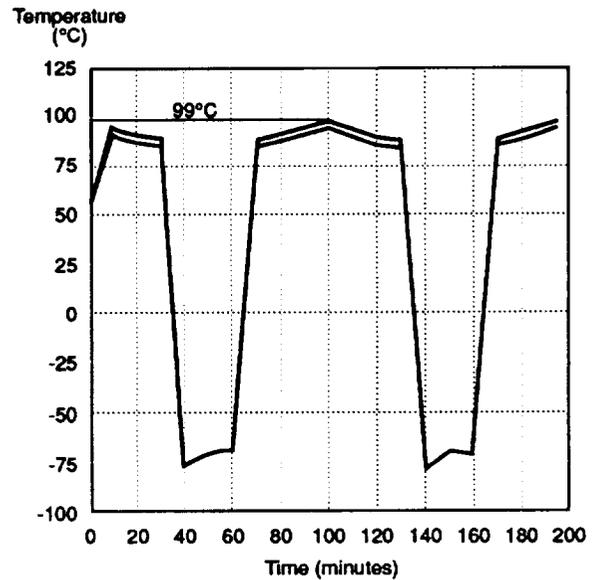


Figure 12. *Astro Edge* Solar Array GaAs Cell Temperature Profile for Worst Case Equatorial LEO.

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SESSION VI

NON-SOLAR ENERGY
CONVERSION

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